VI-based Inverters

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The transition from the synchronous generator (SG)-based conventional power generation to converter-based renewable energy sources (RES) deteriorates the frequency stability of the power system due to the intermittency of wind and photovoltaic (PV) generation. Unlike conventional power generation, the lack of rotational inertia becomes the main challenge to interface RES with the electrical grid via power electronic converters. In the past several years, researchers have addressed this issue by emulating the behavior of SG mathematically via pulse width modulation (PWM) controller linked to conventional inverter systems. These systems are technically known as VI-based inverters, which consist of virtual synchronous machine (VSM), virtual synchronous generator (VSG), and synchronverter.

Synchronverter Solar Photovoltaic System Renewable Energy Sources Inverter
Virtual Inertia Droop Control Power Quality

1. Introduction

As the amount of solar and wind energy generation increases, grid-connected RES requires VI emulation, and thus VI-related publication and research are increasing [[1]]. There are limited studies that compare VI-based inverters, namely virtual synchronous generator (VSG), virtual synchronous machine (VSM) and synchronverter, concerning their technical implementations, merits, demerits, and applications. Given the rising demand for inertia to improve frequency regulation [[2]] as the RES penetration increases, this entry explores and studies the potential of VI for every use in the power grid. The primary objective of this paper is to provide a useful insight into the state-of-the-art VI applicability in RES-dominated power grid quality control and stabilization. This entry presents a comparative review of the various topologies used to implement VI in an inverter.

2. Implementation of VI-based Inverters

Primarily, all of the VI-based inverters are originated from the structure and mathematic model of SM and SG, which can be found in classic textbooks [[3]]. SM is a general term that constitutes both synchronous motors and SG. Hence, VSM, VSG, and synchronverter are identical since the modeling of an SG is similar to SM. As illustrated in Figure 1, a round rotor SG is modeled from its first principles and fundamental formulas, by assuming it has one pair of poles per phase and one pair of poles on the rotor (p = 1). The structure is an ideal two-pole SM consist of combining the circuits of a three-phase stator and a rotor that has a spatial displacement in its rotation.

All the minimal losses, including magnetic-saturation effects, magnetic reluctance, and losses of the iron core and eddy current, are ignored since the model is assumed as a perfect model without any losses for the simplicity [4].

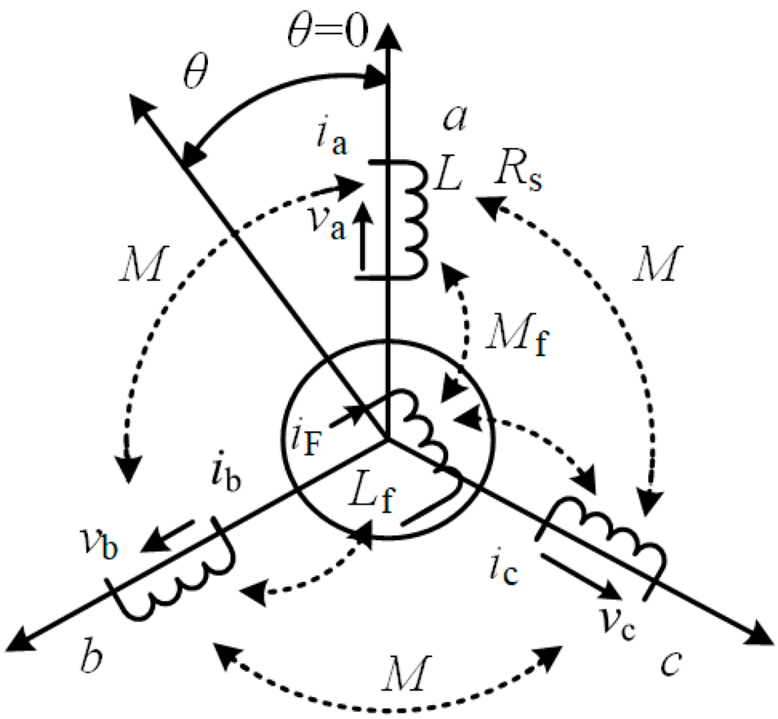

Figure 1. The mechanical structure of an idealized three-phase round-rotor SG.

A conventional inverter with VI emulation is referred to as VSM, VSG, and synchronverter. Synchronous voltage source converter (VSC), virtual synchronous control (VSYNC), synchronous inverter (SI), and synchronous converter are the interchangeable terms. Sometimes, it is also known as a photovoltaic virtual synchronous generator (PVSG) or PV-VSG, which consists of solar PV and SG [5]. The general single line diagram of a grid-connected VI-based inverter is illustrated in Figure 2.

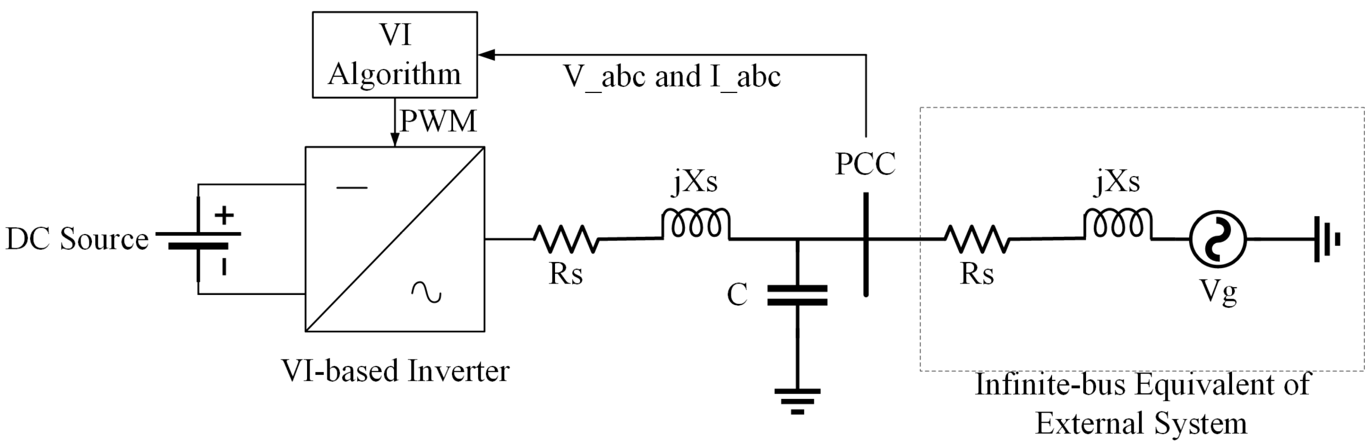

Figure 2. The general single line diagram.

As illustrated in Figure 3, control actions are deployed for a specific time frame to balance the generation and load for frequency control. The figure highlights the main difference between the system with VI and system without VI. The power system with VI has the following advantages:

1. Reduction in frequency nadir and frequency deviation from nominal frequency (f_n)

2. Less overshoot and faster transient or respond time

3. Less RoCoF and less steep gradient

4. Faster recovery time to the nominal frequency

Traditional frequency regulation process and the response of the power system can be divided into three stages, namely primary, secondary, and tertiary frequency response, which is equivalent to inertial response and governor response, automatic generation control (AGC), and reserve deployment, respectively [6]. VI is essential for inertial response in primary control frequency containment process (FCP) to provide dynamic frequency support for the grid with high wind and solar power penetration [7]. Figure 4 illustrates the VI-based inverter is reminiscent of an SG to enable grid-connected RES with the inertial response for stable frequency. Figure 5 presents the general connection of a VI-based inverter in grid-connected RES.

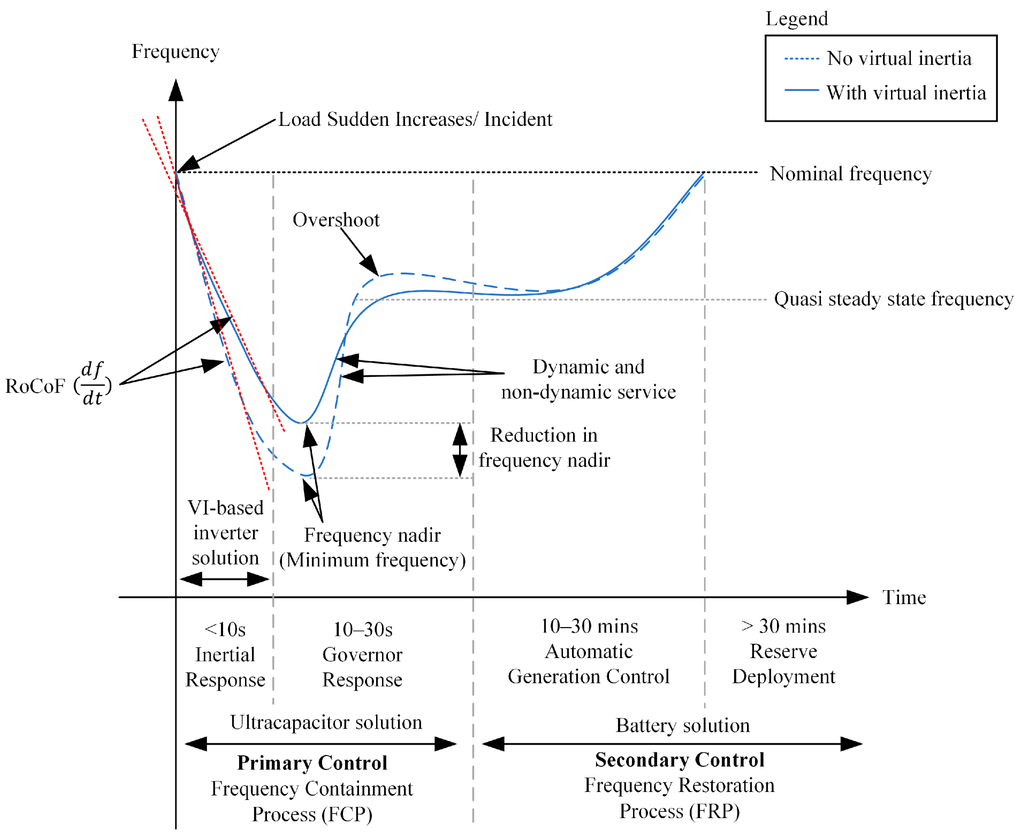

Figure 3. The effect of VI that reduces sudden frequency drop.

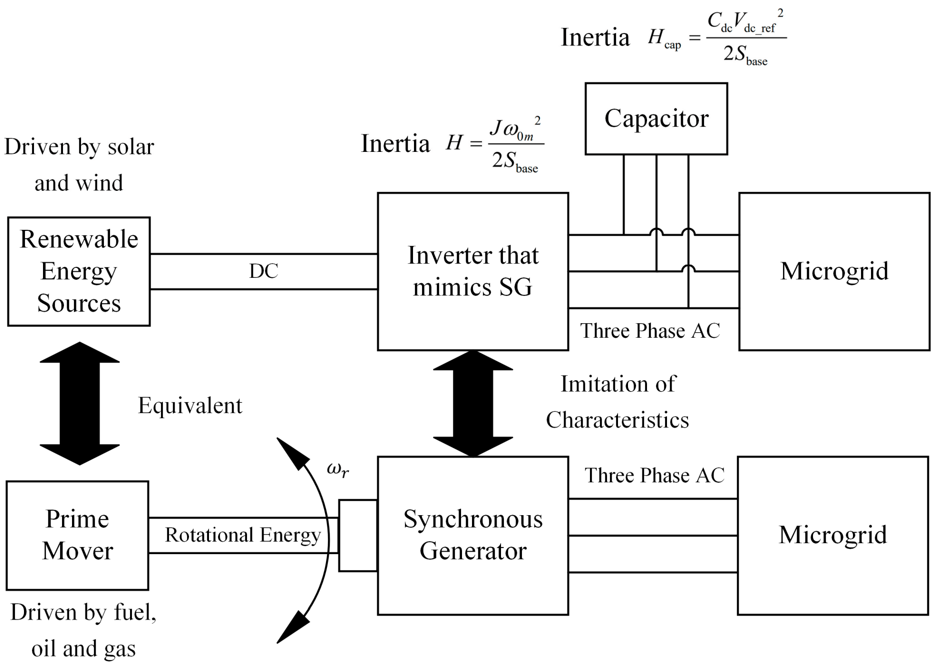

Figure 4. The VI-based inverter enables the imitation of conventional SG-based power system.

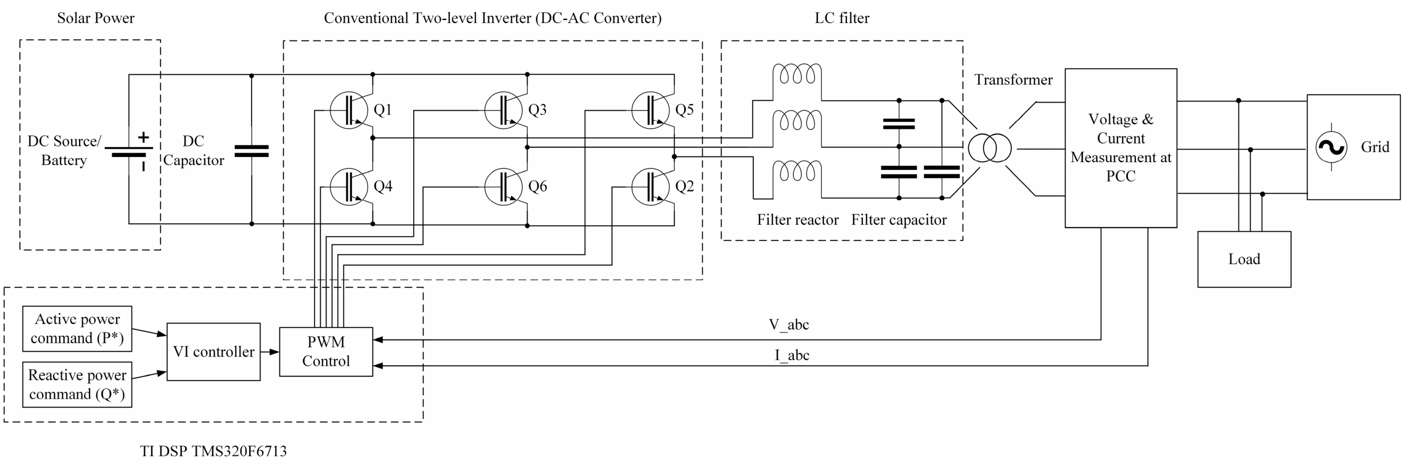

Figure 5. The typical connection of a generic VI-based inverter.

The publication can be found here: https://www.mdpi.com/2076-3417/9/24/5300

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